Indicator: Carbon Storage in Forests (116)

After carbon dioxide is converted into organic matter by photosynthesis, carbon is stored in forests for a period of time in a variety of forms before it is ultimately returned to the atmosphere through the respiration and decomposition of plants, animals, and the paper and wood products that result from tree harvest. A substantial pool of carbon is stored in woody biomass (roots, trunks, and branches). Another portion eventually ends up as organic matter in the upper soil horizons. Carbon storage in forest biomass and forest soils is an essential physical and chemical attribute of stable forest ecosystems.

This indicator, developed by the USDA Forest Service (USDA, 2004), tracks carbon storage in the pools of living and dead biomass in forests in the conterminous 48 states. The carbon pools for this indicator are estimated using USDA Forest Service Forest Inventory and Analysis (FIA) data from five historical periods (circa 1953, 1963, 1977, 1987, and 1997). These data cover 37 states, mostly east of the Mississippi, in the Rocky Mountains, or on the Pacific Coast (Smith et al., 2001). Alaska and Hawaii are not included because of limited historical data. Carbon storage is estimated by the FIA program using on-the ground measurements of tree trunk size from many forest sites and statistical models that show the relationship between trunk size and the weight of branches, leaves, coarse roots (>0.1 inch in diameter), and forest floor litter, combined with estimates of forest land area obtained from aerial photographs and satellite imagery. These values are converted into carbon storages based on the results of previous field studies (Smith and Heath, 2002; Smith et al., 2003; Birdsey, 1996). Forest floor litter includes all dead organic matter above the mineral soil horizons, including litter, humus, small twigs, and coarse woody debris (branches and logs greater than 1.0 inches in diameter lying on the forest floor). Organic carbon in soil is not included.

What the Data Show

The change in carbon inventories from year to year represents the net growth of trees, minus the amount of carbon removed in harvested timber. The average rates of net carbon storage in forests increased between the 1950s and the 1980s, but declined somewhat during the 1990s (Figure 116-1). This trend varies among regions of the country, but net storage has been positive in all regions during the past two decades (Figure 116-2).

The rate of storage for the last period of record (1987-1996) decreased to 135 MtC/yr, with declining sequestration evident in live, dead, and understory pools. This decline is thought to be due to a combination of increased harvests relative to growth, more accurate data, and better accounting of emissions from dead wood (USDA, 2004).

The Northern region is sequestering the greatest amount of carbon, followed by the Rocky Mountain region (Figure 116-2). The trend of decreasing sequestration in the South is due to the increase in harvesting relative to growth. Some of the harvested carbon is sequestered in wood products (USDA, 2004).

Indicator Limitations

- The data include only forest classified as "timberland," which excludes about one-third of U.S. forest land cover. Historical data from Alaska and Hawaii are insufficient for inclusion in this indicator.
- Data are derived from state inventories that do not correspond exactly to the decades identified in Figure 116-1.
- Carbon stored in soil is not included.

- Carbon pools are not measured, but are estimated based on inventory-to-carbon relationships developed with information from ecological studies

These limitations are discussed in detail in Smith and Heath (2000, 2001) and Heath and Smith (2000).

Data Sources

The data sources for this indicator were the Forest Inventory and Analysis, U.S. Department of Agriculture (1979-1995); *and Data Report; A Supplement to the National Report on Sustainable Forests, 2003* U.S. Department of Agriculture, Forest Service (2004). http://www.fs.fed.us/research/sustain/one_pagers/indicator%2027.pdf, http://www.fs.fed.us/research/sustain/documents/Indicator%2027/c5i27.pdf.

References

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Smith, J.E.; Heath, L.S. 2000. Considerations for interpreting probabilistic estimates of uncertainty of forest carbon. In: Joyce, L.A.; Birdsey, R., eds. The Impact of climate change on America's forests. Gen. Tech. Rep. RMRS-59. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 102-111.

Smith, J.E., and Heath, L.S. 2002. Estimators of forest floor carbon for United States forests. Res. Pap. NE-722. Newtown Square, PA: USDA Forest Service, Northeastern Research Station. 37 pp.

Smith, J.E., Heath, L.S., Jenkins, J.C. 2003. Forest volume-to-biomass models and estimates of mass for live and standing dead trees of U.S. forests. Gen. Tech. Rep. NE-298. Newtown Square, PA: USDA Forest Service, Northeastern Research Station. 57 pp.

Smith, W.B., Vissage, J.S., Darr, D.R., Sheffield, R.M. 2001. Forest resources of the United States, 1997. General Technical Report NC-219. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station. 191 pp.

USDA Forest Service. 2004. National Report on Sustainable Forests – 2003. Washington, DC: USDA Forest Service. http://www.fs.fed.us/research/sustain/.

Graphics

Figure 116-1. Average annual net forest carbon storage (Mt/yr) by component, 1953-1996

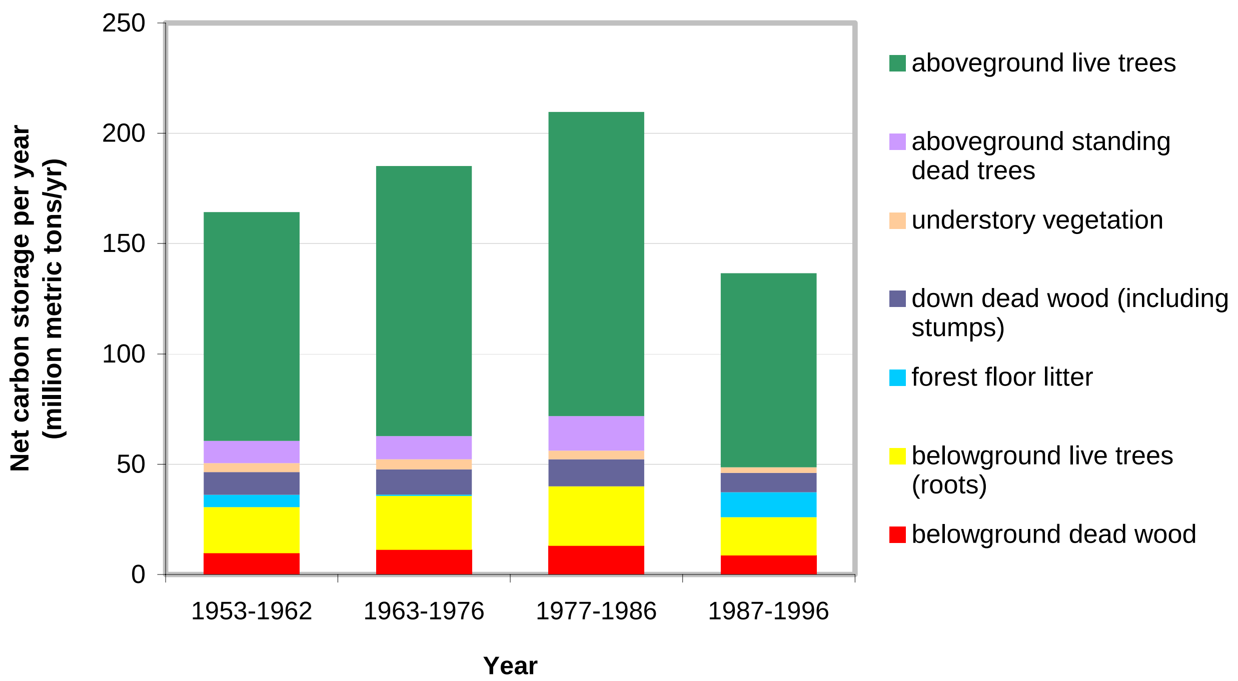
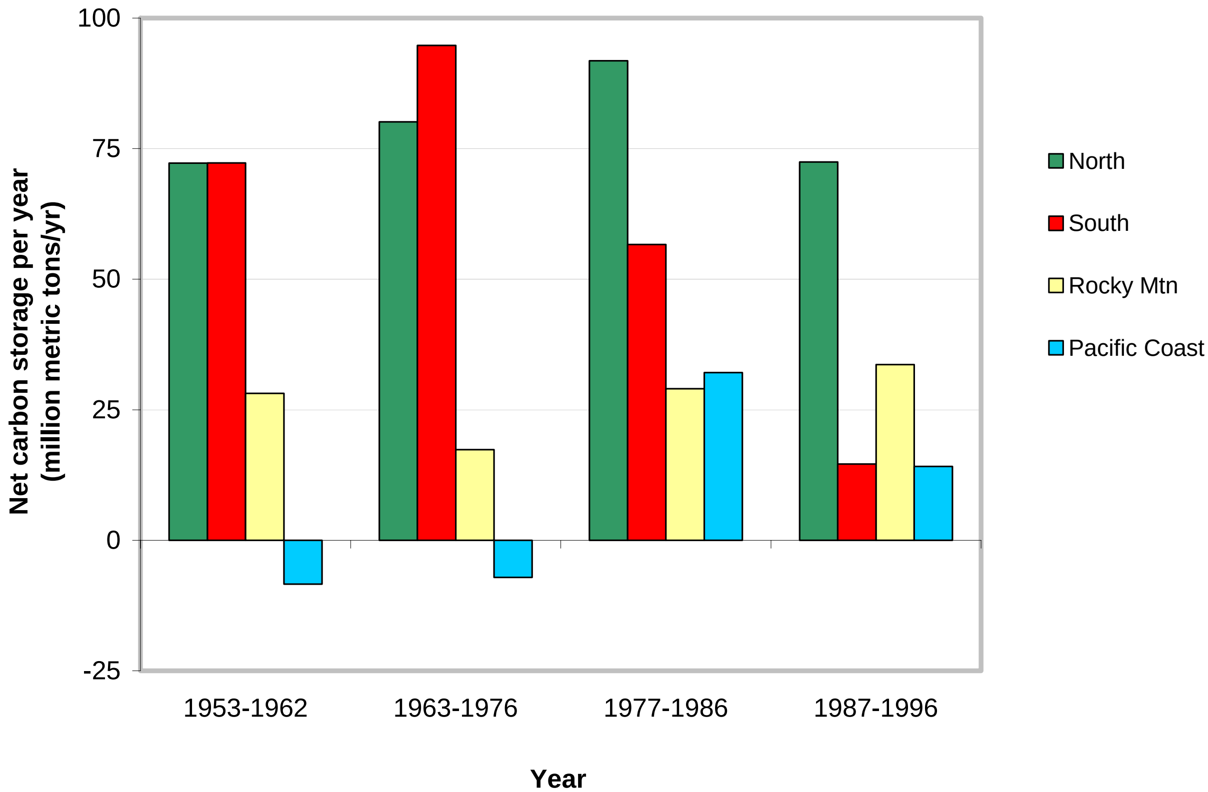


Figure 116-2. Average annual net forest carbon storage (Mt/yr) by region, 1953-1996



R.O.E. Indicator QA/QC

Data Set Name: CARBON STORAGE IN FORESTS
Indicator Number: 116 (89663)
Data Set Source: U.S. Department of Agriculture
Data Collection Date: Irregular: 1953, 1963, 1977, 1987, 1997
Data Collection Frequency: variable
Data Set Description: Carbon Storage in Forests
Primary ROE Question: What are the trends in the critical physical and chemical attributes of the Nation's ecological systems?

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

Yes. The U.S. Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) Program developed this indicator from field measurements of on-ground tree diameter taken throughout the lower 48 states (USDA 2004). FIA describes current (2004) field data collection methodology in procedural manuals available online (http://fia.fs.fed.us/library/field-guides-methods-proc/). These manuals do not include explicit scientific or peer-reviewed support for tree diameter measurement. However, FIA has always employed a consistent methodology for measuring diameter: 4.5 feet from the ground, measured on the uphill side of the tree if it is on a slope. FIA also has a consistent (albeit complicated) way of measuring trees with multiple trunks (Linda Heath, Forest Service, personal communication, 2004). Calculations of total carbon storage require estimations of forest land area, which the Forest Service obtained through analysis of aerial photographs and satellite imagery. Smith et al. (2001) provides documentation of this process. While the Forest Service does not provide explicit scientific support for this methodology, government agencies regularly use aerial image analysis in their efforts to classify land uses, most notably in the National Land Cover Dataset (NLCD), available from USGS.

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

The Forest Service does not present full information about historic sampling design online. FIA methodologies have varied from year to year and from region to region, at least in terms of overall sample grids (Forest Service, Ken Stolte, personal communication, 2004). However, current FIA sampling procedures provide useful information about the general principles by which the FIA program has operated through the years. FIA's current (2004) sampling plan consists of three analytical phases. In Phase 1, the phase of lowest detail, FIA analyzes aerial photographs and satellite imagery to determine general characteristics of forest cover. FIA also uses Phase 1 imagery to plot a grid of locations for ground monitoring in Phase 2. Phase 3 represents a more detailed ground assessment than Phase 2; this monitoring takes place at a subset of Phase 2 locations. FIA has published fact sheets to support and explain this three-tiered sampling methodology: a detailed description of phases (http://fia.fs.fed.us/library/fact-sheets/data-collections/Phase2_3.pdf) and sampling and plot design (http://fia.fs.fed.us/library/fact-sheets/data-collections/Sampling and Plot Design.pdf). According to a general description of the FIA Program at http://fia.fs.fed.us/library/fact-sheets/data-collections/FIA_Data_Collection.pdf, Phase 2 consists of approximately one ground site per 6,000 acres, where data collectors make basic observations about forest characteristics (e.g., age and density) as well as basic measurements like tree diameter. Phase 3 consists of one site per

96,000 acres, where researchers gather more detailed measurements (e.g., tree damage from ground-level ozone) (http://fia.fs.fed.us/library/fact-sheets/data-collections/Phase2_3.pdf). Although FIA presents no documentation to confirm that the FIA program operated under these procedures when it conducted earlier measurements (data for this indicator dates back to 1953), other sources do confirm that FIA has consistently used a similar multi-tiered approach. As noted in Draft ROE/03, p. B-39, FIA has historically monitored about 450,000 Phase 2 sites (roughly every 3 miles), and approximately 125,000 Phase 3 sites. The measurements used to construct this indicator most likely would have come from Phase 2 sites. FIA has documented temporal aspects of sample design, but does not present explicit scientific support. However, additional scientific support for FIA methods may be found in a special issue of the Journal of Forestry (vol.7, no. 12, 1999).

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

Yes. The Forest Service estimates carbon storage from measurements of tree diameter using a series of statistical models that are supported by scientific/peer-reviewed literature (see T3Q1 for complete references). (1) This indicator requires the use of statistical models that show the relationship between trunk size and the weight and volume of branches, leaves, and coarse roots. For this step, the Forest Service uses species-specific "taper models." While models varied over time and from one FIA region to another (Linda Heath, Forest Service, personal communication, 2004), a good general reference for these models is: Hansen, Mark. 2003. Volume and biomass estimation in FIA: national consistency vs. regional accuracy. pp. 109-120. In: McRoberts, R.E., and others. Proceedings of the third annual forest inventory and analysis symposium; 2001 October 17-19; Traverse City, MI. Gen Tech Rep NC-230. St. Paul MN: US Dept of Agriculture, Forest Service, North Central Research Station. 208 pp. (http://ncrs.fs.fed.us/pubs). (2) The Forest Service uses live-tree volumes to estimate carbon reservoirs, following equations derived from ecological studies and described by Smith et al. (2003). The Forest Service estimates carbon in the forest floor using additional models that account for forest area, type, and age (Smith and Heath, 2002). Carbon in understory vegetation is estimated using equations given in Birdsey (1996). In general, the process of converting forest inventory data to carbon through biometrical models is supported by forest scientists as a standard analytical approach (IPCC, 1997; Barford et al., 2001; full citations in T3Q1). (3) The Forest Service divides carbon reservoirs into specific types (e.g., understory, down dead, forest floor) based on standards documented by Smith et al. (2001). For example, Smith et al. defined forest floor litter as all dead organic matter residing above the mineral soil horizons, and considered roots a part of the live tree if they met a basic size criterion (>0.1 inches in diameter).

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

This indicator provides useful information about the function and sustainability of the nation's ecosystems, as net storage of carbon in forests is considered a proxy for forest productivity. The sampling design enables this indicator to represent trends over a relatively large time period, rather than year-to-year. FIA data collection has historically taken place at multi-year intervals (Ken Stolte, Forest Service, personal communication, 2004), and thus far, the data used to generate this indicator represent only five general periods of measurement (circa 1953, 1963, 1977, 1987, and 1997). However, the years chosen for analysis are sufficiently well spaced to enable inter-decadal comparisons. The design also allows for representation of general trends across the lower 48 states (Alaska and Hawaii lack the same level of FIA historical coverage), with one notable limitation: the FIA Program has historically measured only forest land classified as "timberland," which encompasses only two-thirds of the forest area of the lower 48 states. However, within this two-thirds of forest land, FIA samples are collected with uniform spacing and relatively high resolution. FIA Phase 2 and Phase 3 ground measurements are conducted at sites chosen following a grid or hexagon pattern, so as to present results that are well distributed in space (see T1Q2 for discussion of sampling phases). Thus, results may be broken down by region or by forest type. FIA design has varied over time and from region to region, but general principles appear to have remained fairly consistent (e.g., the multi-tiered methodology). Currently, the Forest Service's Forest Inventory and Analysis (FIA) Program assesses approximately 450,000 sites in Phase 2 and 125,000 sites in Phase 3 (see T3Q1 for documentation of FIA field methods), although it may visit a given site only every 5 or 10 years (in some cases, up to 20 years between visits). While the Forest Service (2004) does not discuss spatial sample size for this indicator's data set, descriptions of FIA methodology classify tree diameter as a Phase 2 measurement, suggesting that sample size may be closer to 450,000 sites. Likewise, Phase 2 investigations also record general characteristics used in some of the biomass models, such as forest age and forest type. In addition, FIA treats each site with a high level of detail, as described in the documentation for its database of recent measurements (http://ncrs2.fs.fed.us/4801/fiadb/fiadb_documentation/fiadb_chapter2.htm).

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

The sampling design does not include any special effort to represent sensitive populations or ecosystems. This indicator is designed to offer a very general representation of overall trends in forest growth. While particular forest types are identified during data collection, it is with the intention of ensuring that the statistical methods applied in data transformation are appropriate to the species in question (e.g. ratios of carbon storage to trunk diameter in oak-hickory forest versus scrub pine forest). Nonetheless, the availability of forest type data presents an opportunity for analysis of growth within specific forest types, including those that may be relatively sensitive to environmental stressors.

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

No. However, by its nature, this indicator compares trends in carbon storage and forest growth against what is essentially a reference condition: the condition of no net growth, or zero net carbon storage.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

The Forest Service's FIA Program developed this indicator from field measurements of tree diameter (USDA Forest Service, 2004). FIA describes current (2004) data collection methodology at (http://fia.fs.fed.us/library/field-guides-methods-proc/). FIA also has documented some specific sampling procedures (e.g., the size of sample plots) for data collected in the 1990s and stored in its online database (http://ncrs2.fs.fed.us/4801/fiadb/fiadb_documentation/fiadb_chapter2.htm). While these references do not discuss the full historical range of FIA sampling, they represent the best available online documentation of data collection methods that may have been used by FIA in earlier monitoring studies that contributed to this indicator. The Forest Service cites several analytical methods in its National Report on Sustainable Forests -- 2003 (Washington, DC: USDA FS-766. February 2004.), which is the primary source of data for this indicator (http://www.fs.fed.us/research/sustain/documents/Indicator%2026/c5i26.pdf): Species-specific methods of calculating tree volume from trunk diameter have been used in: Smith, W.B., Vissage, J.S., Darr, D.R., Sheffield, R.M. 2001. Forest resources of the United States, 1997. General Technical Report NC-219. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station. 191 pp. Models have changed over time, and have often differed from one FIA region to another (Linda Heath, Forest Service, personal communication, 2004). However, a good general reference for these models is: Hansen, Mark. 2003. Volume and biomass estimation in FIA: national consistency vs. regional accuracy. pp. 109-120. In: McRoberts, R.E., and others. Proceedings of the third annual forest inventory and analysis symposium; 2001 October 17-19; Traverse City, MI. Gen Tech Rep NC-230. St. Paul MN: US Dept of Agriculture, Forest Service, North Central Research Station. 208 pp. (http://ncrs.fs.fed.us/pubs). Estimation of carbon in live trees, based on volume, is documented in: Smith, J.E., Heath, L.S., Jenkins, J.C. 2003. Forest volume-to-biomass models and estimates of mass for live and standing dead trees of U.S. forests. Gen. Tech. Rep. NE-298. Newtown Square, PA: USDA Forest Service, Northeastern Research Station. 57 pp. Estimation of carbon in the forest floor, based on forest age and type: Smith, J.E., and Heath, L.S. 2002. Estimators of forest floor carbon for United States forests. Res. Pap. NE-722. Newtown Square, PA: USDA Forest Service, Northeastern Research Station. 37 pp. Carbon in understory vegetation, based on forest age and type: Birdsey, R.A. 1996. Carbon storage for major forest types and regions in the conterminous United States. In: Sampson, R.N., Hair, D., eds. Forests and global change, volume 2: forest management opportunities for mitigating carbon emissions. Washington, DC: American Forests: 1-25, 261-308. More information on carbon storage models: Birdsey, R.A. 1992. Carbon storage and accumulation in United States forest ecosystems. Gen. Tech. Rep. WO-59. Washington, DC: USDA Forest Service. 51 pp. Additional documentation (support for the use of biometric methods of estimating carbon storage): (1) Intergovernmental Panel on Climate Change (IPCC). 1997. Revised 1996 Guidelines for national greenhouse gas inventories, vol. 1-3. Paris: IPCC/OECD/IEA. 650 pp. http://www.ipcc.ch/pub/guide.htm. (2) Barford, C.C., Wofsy, S.C., Goulden, M.L. [and others]. 2001. Factors controlling long- and short-term sequestration of atmospheric CO2 in a mid-latitude forest. Science 294: 1688-1691.

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

In Forest Resources of the United States, 1997, Smith et al. (2001) presents aggregate figures of timber volume by state and forest type. This includes historical data for 1953, 1963, 1977, 1987, and 1997. However, due to the fact that data collection occurred in different states in different years, the data represent the most recent data available as of a given year (e.g., "as of 1953"), and not necessarily the data collected within any specific one-year time frame. Smith et al. (2001) does not include either the full set of volume data (by measuring location or by county) or the raw diameter data used for volume calculations. The Forest Service's online FIA database contains detailed datasets by state from the late 1970s through 2003. These datasets include raw data from individual FIA plots (tree diameter, etc.), which were used to generate the most recent aggregate figures (e.g., "forest conditions as of 1997") in Smith et al. (2001). Older aggregate figures in Smith et al. (2001) were based on similar datasets, but these older datasets are not available online. Database location: http://fia.fs.fed.us/tools-data/data/. Some historical data may also be obtained indirectly through FIA's online "map-maker" system, which depicts historical data from individual sampling plots (without revealing exact coordinates of sites, which are kept confidential to protect property rights). The Forest Service does not provide online access to the output of the models it used to calculate the amount of carbon contained within the various components of the forest (live trees, forest floor, etc.). However, these data may be obtained from Linda Heath, who co-authored the National Report on Sustainable Forests - 2003 (lheath@fs.fed.us).

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

The reproducibility of this survey is inherently limited, as it relies upon historical data as a basis for evaluating trends over time. FIA survey design has changed greatly through the years, and documentation of historic sampling may be difficult to find (Linda Heath and Ken Stolte, Forest Service, personal communication, 2004). Nonetheless, the Forest Service (2004) has provided complete documentation of current analytical methods. Therefore, it should at least be possible to reproduce the steps by which volume data were converted to tons of carbon for the recent Report on Sustainable Forests -- 2003. The Forest Service keeps sampling locations confidential in order to protect the identity of property owners (FIA Fact Sheet: http://fia.fs.fed.us/library/fact-sheets/data-collections/Phase2_3.pdf), precluding direct access to the underlying data.

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

Several of the Fact Sheets and Field Guides in FIA's online library contain information about quality assurance and quality control of data (http://fia.fs.fed.us/library/). One document in particular, http://fia.fs.fed.us/library/fact-sheets/data-collections/QA.pdf, provides a thorough discussion of many aspects of the QA/QC process as it relates to field measurements.

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

This indicator requires a great deal of spatial extrapolation, but statistical projections appear to have been employed appropriately. FIA designed its sampling procedure to include enough sampling points to derive an overall result with a particular level of uncertainty and confidence (see T4Q2). Aerial imagery helps ensure that measurements are extrapolated to the appropriate forest area and that generalizations account for the appropriate forest type. Projections are not extended beyond the spatial bounds of the inventory. Thus, FIA does not attempt to provide data for Alaska, Hawaii, or non-timber forest in the lower 48 states (see T4Q4). This indicator does not require temporal extrapolation or generalization, aside from the fact that data are grouped by decade (roughly).

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

The Forest Service's Report on Sustainable Forests -- 2003 does not present uncertainty measurements for the tree measurements upon which this indicator is based. However, FIA's QA/QC fact sheet specifically mentions that field data are always accompanied by uncertainty measurements (http://fia.fs.fed.us/library/fact-sheets/data-collections/QA.pdf). Discussions of uncertainty in forest carbon estimates can be found in two Forest Service publications: Heath, L.S.; Smith, J.E. 2000. An assessment of uncertainty in forest carbon budget projections. Environmental Science & Policy. 3: 73-82. Smith, J.E.; Heath, L.S. 2000. Considerations for interpreting probabilistic estimates of uncertainty of forest carbon. In: Joyce, L.A.; Birdsey, R., eds. The Impact of climate change on America's forests. Gen. Tech. Rep. RMRS-59. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 102-111. FIA's database documentation (http://ncrs2.fs.fed.us/4801/fiadb/fiadb_documentation/fiadb_chapter2.htm) also presents a more general discussion of error in FIA analyses. According to this source, FIA inventories are commonly designed to meet specified sampling errors at the 67 percent confidence limit (one standard error). By Forest Service mandate, sampling error for area must not exceed 3% per 1 million acres; surveys like the one used for this indicator are designed accordingly. For volume and net annual growth, error should be within 5% (Eastern U.S.) or 10% (Western U.S.) per 1 billion cubic feet of growing stock, although these figures are not mandated. This source also quantifies the degree to which error may be magnified on a local scale, suggesting that an indicator like this one is best applied to changes on a regional or national scale.

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

To the extent that this indicator is used to evaluate general national trends, uncertainty and variability should not diminish its utility. Sampling is sufficiently broad and thorough to account for much of the natural variability in tree growth, and according to FIA, error is lowest when this indicator is considered on a large spatial scale -- either national, or a few large regions (FIA database documentation, http://ncrs2.fs.fed.us/4801/fiadb/fiadb_documentation/fiadb_chapter2.htm). If methods of sampling and extrapolation remain consistent over time and space, this indicator should allow regional and inter-decadal comparisons. Nonetheless, the numerical value of this indicator represents several layers of statistical inference whose uncertainties may compound one another. In addition, FIA does not measure every plot during every calendar year, a possible source of temporal uncertainty. Historically, FIA has inventoried different states in different years, and it may only inventory the same state every fifth or tenth year (source: various FIA documents linked from FIA's website, http://fia.fs.fed.us/). In some cases, the interval may even be as great as 20 years (Forest Service, Ken Stolte, personal communication, 2004). The National Report on Sustainable Forests -- 2003 (USDA Forest Service, 2004) classifies data as belonging to five base years (1953, 1963, 1977, 1987, 1997), but not all measurements were actually made in these years. For example, the 1953 dataset does not just include data from states that FIA analyzed in 1953. Instead, this dataset covers all states, using the most recent measurements that were available in 1953. FIA methods have varied over time and between regions -- including criteria like minimum tree size for measurement and the degree to which sample design includes relatively inaccessible areas (Linda Heath, Forest Service, personal communication, 2004). Considering these additional sources of uncertainty, the carbon storage indicator is probably best suited to remain an indicator of general spatial and temporal trends, rather than a specific numerical indicator of forest growth rates. A useful discussion of assumptions in this indicator appears in: Birdsey, R.A. and Heath, L.S. 2001. Forest inventory data, models, and assumptions for monitoring carbon flux. P. 125-135. In: Lal, R., ed. Soil Carbon Sequestration and the Greenhouse Effect. SSSA Special publication No. 57. Soil Science Society of America, Inc. Madison, WI. 236 pp.

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

There are several limitations. (1) This indicator does not cover all forest land in the United States. Alaska and Hawaii are excluded entirely because of limited historical data, while land in the other 48 states is only counted if it is classified as "timberland" (about two-thirds of total forest land in the lower 48). Thus, this indicator excludes national park land and other protected or reserved land, or roughly one-third of forest land cover in the lower 48 states. (2) Certain forest types may be underrepresented. In particular, this indicator may under-count western pinyon and juniper forests (Houghton et al., 1999; full citation below). Classification as "forest" is dependent on aerial imagery, so it is possible that some very thin or marginal forest land may not be counted.

[Houghton, R.A., Hackler, J.L., Lawrence, K.T. 1999. The U.S. carbon budget: contributions from land-use change. Science 285: 574-578.] (3) The model may not accurately reflect a large increase in the volume of dead wood in certain forest areas due to increased fire suppression in recent years (Houghton et al., 1999). (4) This indicator does not include any accounting of carbon in soil, another carbon sink. According to the Heinz Center (personal communication, 2004), there simply are not enough data available to characterize soil carbon for the same historical range as the rest of this indicator. (5) Data have improved dramatically since the 1950s. Linda Heath of the Forest Service (personal communication, 2004) notes that for early years (1953, 1963, etc.), the best volume data available for the National Report on Sustainable Forests -- 2003 were aggregate tree volumes for each state, not records of individual trees or plots. Thus, the recent decrease in carbon sequestration (evident in the graphic for this indicator) may actually be a reflection of better data rather than exact trends.